

central position and, hence, to the displacement of the levitated object from the nominal levitation position. The main shortcomings of such an apparatus are associated with the laser: Lasers tend to be expensive, and laser beams are often characterized by poor spatial distribution (speckle) and by poor short-term spatial and temporal stability.

The basic principle of operation of the improved optoelectronic position-measuring apparatus is the same as that of the prior apparatus described above,

except that the laser is replaced with an incandescent light bulb and associated optics (see figure). Unlike the light from a laser, the light from an incandescent lamp is not subject to mode shifts and, hence, is spatially and temporally stable in the short term. The spatial distribution of light is better for the intended application because there is no speckle and the illumination is approximately constant across the levitation region. Unlike the light from a laser, the light from an incandescent lamp varies smoothly with applied

power and is thus more easily controllable. Finally, a light bulb is easily replaceable and costs much less than does a laser.

This work was done by Robert Hyers, Larry Savage, and Jan Rogers of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Benita Hayes, MSFC Commercialization Assistance Lead, at benita.c.hayes@nasa.gov. Refer to MFS-31535.

Compact Tactile Sensors for Robot Fingers

Simple, rugged, compact sensors measure spatial distributions of contact forces.

Lyndon B. Johnson Space Center, Houston, Texas

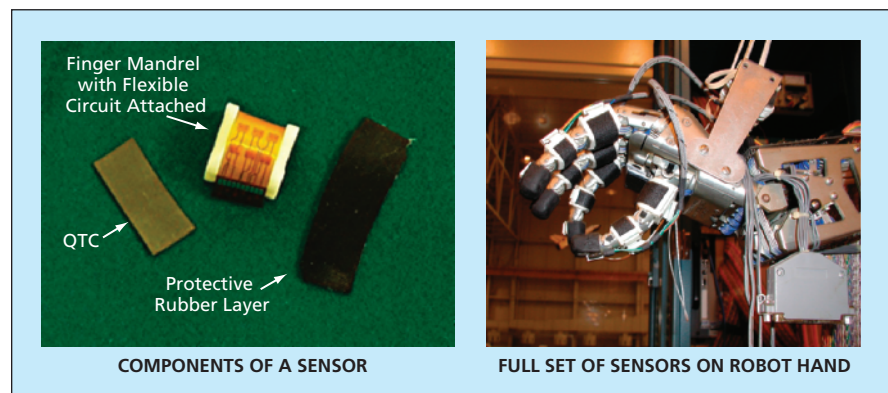
Compact transducer arrays that measure spatial distributions of force or pressure have been demonstrated as prototypes of tactile sensors to be mounted on fingers and palms of dexterous robot hands. The pressure- or force-distribution feedback provided by these sensors is essential for the further development and implementation of robot-control capabilities for humanlike grasping and manipulation.

Each sensor (see figure) includes a hard mandrel designed to fit over a finger segment or a palm. A flexible circuit that includes an array of electrodes is attached to the mandrel and is overlaid with a force-sensitive rubber denoted quantum-tunneling composite (QTC). A protective layer of non-sensory rubber is placed over the QTC.

Each electrode defines a tactile sensor point denoted a tactel in analogy to a

pixel (picture element) in an image-detecting array of photodetectors. In addition to the electrodes, the sensor includes a ground conductor common to all the elements of the array. The local electrical resistivity of the QTC changes in response to local pressure. By use of simple electronic circuits (e.g., resistive voltage dividers), the local changes of resistance in the tactels are converted to voltages. The voltages can be read by use of external analog-to-digital converter circuitry, then processed into forces or pressures on the tactels. Hence, the processed sensor output indicates the spatial distribution of force or pressure at the spatial resolution of the tactels.

This work was done by Toby B. Martin of Johnson Space Center; David Lussey of Peratech, Ltd.; Frank Gaudiano, Aaron Hulse, Myron A. Diffler, and Dagoberto Rodriguez of Lockheed Martin Corp.; Paul Biel-ski of Titan Systems Corp.; and Melisa Butzer of Oceaneering Space Systems. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23608/93



A Sensor for a Finger includes a hard mandrel that fits over the finger and that supports a flexible circuit overlaid by a QTC overlaid by protective rubber.

Improved Ion-Channel Biosensors

Improvements include greater stability and greater signal-to-noise ratios.

NASA's Jet Propulsion Laboratory, Pasadena, California

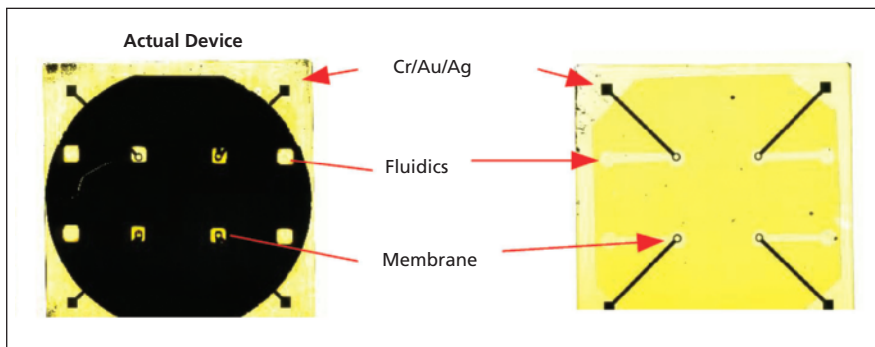
An effort is underway to develop improved biosensors of a type based on ion channels in biomimetic membranes. These sensors are microfabricated from silicon and other materials compatible

with silicon. As described below, these sensors offer a number of advantages over prior sensors of this type.

To place these advantages in context, it is first necessary to present some back-

ground information on prior sensors of this type:

- Ion channels of the type in question are very sensitive to a wide variety of ligands, to which they respond by gen-



An Array of Four Wells containing sensor structures was fabricated in a silicon wafer of 4-in. (≈ 10 -cm) diameter to demonstrate the ability to make an array of multiple sensors on a single chip. Each sensor is electrically addressed, separately from the other sensors, via its electrodes.

erating specific electrical signals. Consequently, such ion channels would be ideal bases for biosensors if they could be constructed in arrays and made stable and electrically addressable.

- Unfortunately, such ion channels function only within biological or biomimetic membranes, the life spans of which, heretofore, have usually been no more than several hours. In addition, their small signals (currents of 1 to 10 pA) make it necessary to mount them on platforms along with, and coupled to, low-noise, highly-amplifying electronic circuits. These characteristics have posed difficulties that have limited the commercial development of ion-channel biosensors.
- Heretofore, the standard design of one commercial product line of ion-channel recording devices has provided for lipid-bilayer recording chambers. Such chambers are suitable for short-term (1 to 2 hours) recording only and are not constructed in arrays. Another commercial product line of ion-channel biosensors offers

the stability needed for longer-term recording, but operation is limited to DC capacitive measurements.

The figure presents top and bottom views of a prototype array of four of the developmental sensors fabricated in a silicon wafer on a glass plate. Each sensor in the array can be individually electrically addressed, without interference with its neighbors. Each sensor includes a well covered by a thin layer of silicon nitride, in which is made a pinhole for the formation of lipid bilayer membrane. In one stage of fabrication, the lower half of the well is filled with agarose, which is allowed to harden. Then the upper half of the well is filled with a liquid electrolyte (which thereafter remains liquid) and a lipid bilayer is painted over the pinhole. The liquid contains a protein that forms an ion-channel on top of the hardened agarose. The combination of enclosure in the well and support by the hardened agarose provides the stability needed to keep the membrane functional for times as long as days or even weeks.

An electrode above the well, another electrode below the well, and all the materials between the electrodes together constitute a capacitor. What is measured is the capacitive transient current in response to an applied voltage pulse. One notable feature of this sensor, in comparison with prior such sensors, is a relatively thick dielectric layer between the top of the well and the top electrode. This layer greatly reduces the capacitance of an aperture across which the ion channels are formed, thereby increasing the signal-to-noise ratio. The use of a relatively large aperture with agarose support makes it possible to form many ion channels instead of only one, thereby further increasing the signal-to-noise ratio and effectively increasing the size of the available ionic reservoir. The relatively large reservoir makes it possible to measure AC rather than DC.

This work was done by Jay Nadeau, Victor White, Dennis Dougherty, and Joshua Maurer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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